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CIVIL AERONAUTICS BOARD

AIRCRAFT ACCIDENT REPORT

ADOPTED: July 26, 1962 **RELEASED** July 31, 1962

EASTERN AIR LINES, INC., LOCKHEED ELECTRA L-188, N 5533,
LOGAN INTERNATIONAL AIRPORT, BOSTON, MASSACHUSETTS, OCTOBER 4, 1960

SYNOPSIS

On October 4, 1960, at 1740 e.d.t., an Eastern Air Lines Lockheed Electra, N 5533, crashed into Winthrop Bay immediately following takeoff from runway 9 at Logan International Airport, Boston, Massachusetts. Ten of the 72 persons aboard survived the crash. The aircraft was totally destroyed.

A few seconds after becoming airborne, the aircraft struck a flock of starlings. A number of these birds were ingested in engines Nos. 1, 2, and 4. Engine No. 1 was shut down and its propeller was feathered. Nos. 2 and 4 experienced a substantial momentary loss of power. This abrupt and intermittent loss and recovery of power resulted in the aircraft yawing to the left and decelerating to the stall speed. As speed decayed during the continued yaw and skidding left turn, the stall speed was reached; the left wing dropped, the nose pitched up, and the aircraft rolled left into a spin and fell almost vertically into the water. An altitude of less than 150 feet precluded recovery.

The Board determines that the probable cause of this accident was the unique and critical sequence of the loss and recovery of engine power following bird ingestion, resulting in loss of airspeed and control during takeoff.

Investigation

N 5533, a Lockheed Electra, had arrived in Boston at 1533[1/] on October 4, 1960, as Eastern Air Lines Flight 444 from New York City. The aircraft and its crew were scheduled for turn-around and were to depart as Flight 375 to Philadelphia, Pennsylvania; Charlotte, North Carolina; Greenville, South Carolina; terminating at Atlanta, Georgia.

There were sixty-seven passengers and a crew of five aboard Flight 375. Fifty-nine passengers and three crew members sustained fatal injuries. Nine of the ten survivors received serious injuries.

Routine preparations for the flight, which included filing ~~an Instrument~~ Flight Rules (IFR) flight plan to Philadelphia via Victor Airways 3 and 147 at 10,000 feet, were completed by the crew.

1/ All times herein are Eastern Daylight based on the 24-hour clock.

FAA [illegible]

No maintenance was necessary during the turn-around. The aircraft was serviced for the flight to a total of 24,900 pounds of fuel and the total gross weight at the ramp was calculated to be 97,987 pounds. This weight was properly distributed with respect to the center of gravity and was well below the maximum allowable for this aircraft.

Flight 375 departed the ramp at 1735. It was issued an IFR clearance in accordance with its flight plan with instructions to cross Natick Intersection at 3,000 feet and to maintain runway heading for two minutes after takeoff. The flight taxied to runway 9 where takeoff was commenced at approximately 1739.

Takeoff airspeeds computed for this flight based on the conditions present at the time were: V_1 104 knots; V_R 116 knots; V_2 121 knots.

The weather observation taken at the time of the accident as reported by the U. S. Weather Bureau was: 6,000 feet scattered; 12,000 feet scattered; visibility 15 miles; wind east-southeast 11 knots. The weather is not considered a factor in this accident.

Numerous groundwitnesses were interrogated as to their observations of the flight during its takeoff and crash. A probable flightpath and sequence of events have been developed from the statements of these witnesses.[2] The aircraft taxied to runway 9 in a normal manner. Takeoff was commenced and the aircraft lifted off the runway after a ground roll of about 2,500 feet and attained a height of 30 to 40 feet. It continued at this height in nearly level flight for a distance of several hundred feet before establishing a normal climb attitude. During this time the landing gear was retracted after which the airplane climbed straight ahead for a short interval. While the airplane was in this initial climb several of the witnesses observed an unusual puff of gray smoke from engine No. 1; others saw a ball of fire from engine No. 2. None of the witnesses saw these indications of trouble from both engines.

During this climb several persons described the aircraft as veering to the left and then returning to its original course; its speed was described as very slow. After reaching an altitude of 100 to 200 feet the aircraft made a flat left turn from the runway heading of 090 degrees magnetic to a heading of about 030 degrees. While on this heading the aircraft maintained its nose-high attitude but appeared to settle approximately one-half the height it had attained.

Two witnesses adjacent to the takeoff area of runway 9 snapped photographs of the aircraft at this point in the flightpath. Assessment of the first picture confirms that the aircraft was on a heading of 030 degrees magnetic, at an altitude of 121 feet m.s.l., and had reached a position approximately 7,000 feet down the runway but was displaced about 1,350 feet to the north. It also appears that the deck angle at the time was about 9 degrees above the horizontal and the aircraft was at an angle of bank of 8.5 degrees to the left. The second photograph, taken about one second later, was also assessed. This photograph showed the airplane to be at an altitude of 121 feet m.s.l., on a heading of 030 degrees magnetic as before; however, at this time the deck angle had increased to 14 degrees and the angle of bank to 14 degrees. Witnesses testified that the aircraft was then seen to execute a maneuver most closely described as a wing-over. During this maneuver the nose came up higher while the left wing dropped to near vertical.

2/ See Attachment "A".

The nose then fell through rapidly and the aircraft descended, striking the water almost vertically and while still rotating to the left. The impact area was in Winthrop Bay approximately 2,000 feet to the left of the centerline of runway 9 and approximately 7,000 feet from the point takeoff was started. The time of impact was calculated as 1740 or 47.5 seconds after takeoff was commenced.

Three persons, all experienced pilots, aboard an Aero Commander approaching runway 15 for landing had an excellent view of the Electra's takeoff. Their attention had been attracted to it because they knew that their landing was to follow the Electra's passing the intersection of runways 9 - 15. They first observed the departing aircraft, already airborne, at about the time it passed the intersection. They noted that the Electra appeared to be starting a left turn well before crossing the end of the runway and assuming a noseup angle which they considered excessive. Thus, their attention was concentrated on the Electra until its contact with the water. The altitude of the Aero Commander was approximately 400 feet when its occupants first observed N 5533, and thereafter decreased normally, commensurate with a landing approach. These three men stated that N 5533 never attained an altitude equal to that of their aircraft. The copilot stated that he saw either a puff of smoke or flame come from the No. 2 nacelle shortly after the Electra passed runway 15. The passenger also observed this emission but described it as a white puff of smoke.

Nine of the ten survivors were interviewed, and their descriptions generally corroborate the statements of the witnesses on the ground and in the Aero Commander. Both stewardesses, seated on the left side of the lounge, felt a considerable amount of vibration shortly after becoming airborne. Both recalled "a sudden burst of power" following their initial realization of trouble; both felt a sharp left turn; one recognized the sound of the engines as "unsynchronized."

Four of the passengers interviewed indicated a sharp, flat turn to the left shortly after becoming airborne. One passenger, seated amidship on the right side stated, "one of the engines on the left side 'shot' some flames off." Another, seated in the right rear of the cabin, recalled feeling a slight "bump," unlike that associated with wheel retraction, shortly after takeoff. Looking out the right window he saw a pattern which he described as a dark smudge and which he said passed through the propeller arc and over the engine nacelle. A former military pilot, seated in the lounge opposite the stewardesses, stated that "shortly after takeoff, something happened to the engines on the left side." While he could not recall specifically, he said his awareness of trouble was through a combination of that which he felt and heard. He was most conscious of the difference between noise of the left engines and the right engines. He also estimated that the time from lift-off to the skidding left turn was about five to seven seconds.

Shortly after the accident, Board investigators received a report that a number of bird carcasses had been found on the runway. Bodies and pieces of bodies representing approximately 75 birds, identified as starlings, were scattered predominantly on the left side of runway 9 between the intersections of taxiway 33 and runway 33. The remains were strewn over an area roughly 400 feet long by 200 feet wide, the midpoint of which was about 3,800 feet from the approach end of runway 9. After autopsies of the birds several ornithologists as well as personnel from the U.S. Fish and Wildlife Service concluded that they had been killed during the late afternoon of October 4.

The U. S. Coast Guard maintained security of the impact area throughout the night following the accident and was instrumental in the initial efforts to recover the wreckage. Recovery operations were conducted by the U. S. Navy and the wreckage was transported to a warehouse for study. It was determined that the aircraft struck the water almost vertically but slightly left wing first and while still rotating to the left about its longitudinal axis. The Nos. 1 and 2 engines broke up and over the left wing and Nos. 3 and 4 broke down and under the right wing. All flight control surfaces were recovered. Impact marks made by the aileron counterweights on rear spar vertical stiffeners indicated the left aileron was in the neutral position at the time of left wing breakup. Corresponding marks made by the right aileron counterweights indicated that this aileron was displaced downward about one-third of its travel when the right wing struck the water. The elevator and rudder surfaces were undamaged prior to salvage and the position of each at impact was indeterminable.

Control cables, push-pull rods, and linkage from the surfaces to the boost packages showed no abnormal conditions. Damage noted in these areas was determined to be the result of impact forces. The landing gear was found in the fully retracted position. The wing flaps were found at the takeoff setting and were symmetrical.

Several feathers were found in the nacelle air scoops[3/] which supplied cooling air to the generators and oil coolers of engines Nos. 1 and 4. In addition one gull feather was found in the cooling duct to the generator of engine No. 3.

All four engines and propellers were recovered from the bay. The No. 1 propeller was fully feathered and the engine was not operating at time of impact. Engines Nos. 2, 3, and 4 were operating at impact and their propellers were found at approximate blade angles of 40, 41, and 41 degrees, respectively. Mechanically, all four engines were found to be in good condition with the exception of impact damage. No. 1 engine showed no rotational damage to the compressor and turbine sections, whereas the remaining engines displayed extensive rotational damage to the rotors from impact. There was no evidence of over-temperature in any of the engines and all appeared capable of normal operation prior to impact.

Numerous samples of foreign matter were removed from the different sections of the gaspaths of the four engines. The specimens removed from the Nos. 1, 2, and 4 engines contained a small amount of material identifiable as bird remains, i.e., tissue and feathers. Some of the feather fragments were identified as starling feathers. There was substantially more of this material in No. 1 engine than in Nos. 2 and 4. Portions of the material not identified as bird remains consisted primarily of metal particles, carbon and marine life. There was no evidence of bird remains found in any of the sections of the gaspath of the No. 3 engine.

There was no evidence of any malfunction or failure in any of the propeller reduction gear assemblies or actuating mechanisms. All appeared to have been capable of normal operation prior to impact.

The No. 1 emergency shutoff handle, which is located in the cockpit, had been pulled. Actuation of this handle feathers the selected propeller, electrically closes the oil tank shutoff valve, and stops the engine fuel flow by closing

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3/ The nacelle air scoop is located on the bottom of the nacelle whereas the engine air inlet is at the top.

the cutoff valve in the fuel control and at the firewall. The Nos. 2, 3, and 4 manual shutoff handles had not been actuated. Both the autofeather system and the manual emergency shutoff levers require electrical power to complete the feather process. The time required to feather is approximately eight seconds at 120 knots.

Most of the aircraft instruments and systems components were recovered. Readings of all instruments were taken immediately upon recovery and the instruments were then disassembled to determine extent of damage and reliability of the readings. All instruments were subjected to ultraviolet light examination to determine, if possible, whether any marks were made by instrument pointers at impact. The results of this examination were negative.

Various readings of engine operating parameters were noted:

Engine Number	1	2	3	4
Turbine Inlet Temperature (^{o}C)	400	978	950	960
Torquemeter Gauge (SHP)	-850	3350	3360	3540
Torquemeter Phase Detector (SHP)	-875	3315	3310	3555

All fuel flow indicators were recovered; however, it was determined that the readings were subject to change after impact and were therefore inconclusive.

All four engine-driven AC generators were recovered; however, the bell housing for the No. 1 was missing due to impact. Detailed examination of the generators showed no indications of any in-service failures. The examination of generators Nos. 2, 3, and 4 showed circumferential scoring of the air inlet hoods by the cooling fans over arcs from 30 to 60 degrees which indicated generator rotation at the time of impact.

The emergency inverter which operates automatically when all four generators are off the line was not rotating at impact. This inverter will come up to speed in about 1 to 2 seconds following disruption of AC power to the Essential AC Bus (which can only occur if all four generators drop off the line). After AC power is restored to the Essential AC Bus the emergency inverter is automatically deactivated. Under these conditions the time for the inverter rotation to coast to a stop is approximately 13 seconds.

The two approach horizon flight instruments which are electrically powered from Priority Bus A were recovered. Inspection and disassembly of these units revealed almost identical readings; the positions of both indices were registering a left bank of 150 degrees at impact.

The two Collins Course Indicators were recovered in relatively good condition. The azimuth rings of the instruments indicated 319 degrees and 311 degrees. Because of the extensive gear reduction in these instruments the readings are considered reliable. Both of these instruments receive electrical power from Priority Bus A.

Examination of the three hydraulic boost control packages did not reveal any conditions which would have precluded normal operation prior to impact. The damage to these units, which occurred at impact or during recovery operation, consisted of ruptured diaphragms and a bent elevator piston rod.

The boost control systems are actuated by two independent hydraulic systems. Either system is capable of handling all hydraulic boost control demands. Three electrically driven hydraulic pumps supply pressure for the two systems. Pumps 1 and 1A serve system No. 1 and pump No. 2, system No. 2. Pumps 1A and 2 receive electrical power from Priority Bus A; pump 1 from Priority Bus B. A standby pump is incorporated in the No. 2 system and receives its power from whichever bus was supplying the pump it replaces.

Examination of the hydraulic pumps and filters showed extensive corrosion due to water immersion; however, these components were free of any evidence of operating failure or damage prior to impact.

Passenger seats, except 19C and 19D, and the lounge seats, all located in the rear of the cabin, failed at impact and were torn from their mounts. In most cases initial failure occurred at the wall attachment followed by failure of the plate on the bottom of the aisle side of the seat. The seats then left the floor forward and upward at an angle of about 20 degrees. In addition, 14 of the 33 center seat belt attach fittings, common to both seat belts in the double seats, failed completely. In seven others there were partial failures Many of the service trays mounted on the backs of seats showed evidence of having been struck from the rear.

As stated before, several eyewitnesses reported seeing smoke or fire emitted from the engines. This evidence, together with that of the bird remains found in the engines during teardown, indicated a need for more information concerning engine operation after bird ingestion. A series of tests was conducted by the Allison Division of General Motors, the engine manufacturer, in which starlings were introduced into an operating engine in varying numbers and sequences. In view of its immediate availability, a static test stand was utilized. Although the test was limited in simulating the in-flight engine response to ingesting birds, much valuable information was obtained. The tests demonstrated that substantial power interruptions and emissions of flame from the tailpipe would occur when starlings were ingested; however, quantitative information was lacking with respect to the engine behavior under flight conditions.

Subsequently another test program was incorporated in the study of the broad problem of turbine engine bird ingestion being conducted under the auspices of the Federal Aviation Agency. In cooperation with Board personnel, the test program was planned to provide information pertinent to the circumstances which prevailed at the time of the accident. These tests were conducted in the Lockheed Aircraft Corporation wind tunnel in Burbank, California. An Electra QEC[4] was installed with modifications in the inlet duct to permit controlled introduction of birds. Various numbers of starlings were ingested into the engine at different power settings and tunnel speeds. Pertinent operating parameters were recorded during each test. Besides substantiating the results of the static test stand program, these tests afforded the following information:

1. The Allison model 501-D13 engine demonstrated excellent resistence to structural damage from starling ingestions.

4/ QEC - "Quick Engine Change" - Allison 501-D13 engine, equipped in this case with an Aeroproducts 606 propeller, mounted in the forward detachable section of the nacelle.

2. Single-starling ingestion at cruise and takeoff conditions revealed negligible power interruption and approximately 90 percent of pre-test power was recovered.

3. Two-starling ingestion at cruise power decreased shaft horsepower approximately 15 percent after recovery; at takeoff power, approximately 10 percent. In both cases, at least 50 percent power was always available.

4. Four-starling ingestion at takeoff power decreased shaft horsepower approximately 15 percent after recovery. Power fell to approximately 500 SHP and was below 50 percent rated from one to three seconds. An autofeathering signal occurred in one of the three tests conducted.

5. Six-starling ingestion at takeoff power decreased shaft horsepower approximately 23 percent after recovery. In one instance, the engine failed to recover. In another test less than 50 percent power was available for four seconds. In the last test the engine flamed out, relighted and produced 50 percent or more power after seven seconds. All tests indicated that autofeathering would occur.

6. Eight-starling ingestion at takeoff power produced an autofeather signal in all three tests. The engine failed to recover in two of the tests. In the remaining instance the engine flamed out, relighted and partially recovered when surging and overtemperature necessitated shutdown.

7. Ingestion of eight starlings in time-sequenced groups of four each critically complicated the recoverability of the engine. One test terminated in shutdown because of surging and overtemperature. In the other test, the engine flamed out, relighted and recovered steady 50 percent or more power after a 10-second interruption. In both instances the propeller would have autofeathered.

The Board extracted information from reports of bird strikes experienced by commercial air carriers. During the period, February 25, 1961, to September 13, 1961, fourteen bona fide bird strikes were reported on the 501-D13 engine. In all instances, the damage proved to be minor. The most critical flight regime was takeoff. The majority of bird strikes (57 percent) including three multiple strikes occurred at this power setting. In a multiple strike involving all four engines, only one engine experienced a slight decrease in horsepower; however, the other multiple strikes, each involving two engines, autofeathered a propeller in both instances. Most of the bird ingestions at takeoff power (62 percent) resulted in an engine shutdown in which the propeller was usually autofeathered (80 percent); engines which recovered after ingestion experienced 100 to 250 HP deterioration in rated power. The nature of inflight ingestion precluded any accurate determination of bird number and/or weight required to cause an engine shutdown. In flight regimes other than takeoff, the bird ingestions caused neither an engine shutdown nor a reported loss in power.

Analysis and Conclusions

The bird remains extracted from the engines and the carcasses which were found on the runway provided evidence that during takeoff starlings were ingested by engines Nos. 1, 2, and 4. The Board concludes that the No. 3 engine did not ingest any birds, because detailed examination of material specimens from its

interior revealed no traces of bird remains. The possibility that sea life may have destroyed the bird remains in No. 3 engine was considered and discarded. All engines were removed from the water within a few hours, with No. 3 being first; consequently the exposure of all the engines to sea life was about the same.

Evaluation of the results of the bird ingestion tests indicates that these tests reasonably simulated engine behavior in flight. This is further substantiated by a number of reports of bird ingestions which have occurred subsequent to this accident. Apart from possible structural damage, birds ingested into the engine affect power output by blocking airflow, decreasing compressor airfoil efficiency with surface debris, distorting gaspath, etc. Component efficiency may deteriorate until the engine is unable to provide external power or is even incapable of surge-free steady operation. It also appears that ingestion of more than three starlings can actuate the autofeather system, cause engine flameout, or reduce the power substantially for several seconds. Engine recovery after ingesting eight or more starlings simultaneously appears very improbable. Post-test inspections indicate that bird debris lodges within the engines after an ingestion.

No. 1 propeller was feathered, most probably by a thrust sensitive signal, generally known as autofeather. The thrust sensitive signal is produced when the power lever is advanced beyond 75 degrees, the system is armed by a switch in the cockpit, and propeller thrust decays below 500 pounds. Autofeathering of any one propeller disarms this feature from the remaining propeller systems, which would account for a like action not occurring to any of the remaining propellers. Autofeathering of No. 1 propeller further suggests that its engine was the first to be materially affected by bird ingestion and that at least four birds were ingested.

It is believed that No. 2 engine ingested about six birds; consequently, its power was the most adversely affected of all the engines, excluding the autofeather action of No. 1 propeller. Since no direct method is available to determine the number of birds ingested by an engine, this conclusion is induced from several factors. The obviously critical and rapid deterioration of airplane performance and the initial yaw to the left after penetrating the flock of starlings indicated a prolonged substantial power interruption on the left side. In addition, witnesses observed flames emitting from an engine on the left wing and several specified the No. 2 engine. This is further substantiated by recalling that the No. 1 engine was shut down in conjunction with the autofeather action. The flames emitted from the tailpipe of No. 2 engine indicate a torching relight after a flame-out. The flames emitted during engine surges observed in tests appear to be too short to extend through the long exhaust duct in the Electra installation. The only conclusion compatible with all the circumstances of this accident is that No. 2 engine ingested about six birds, flamed out, relighted and recovered substantial power within several seconds. Tests indicate that less than 50 percent rated power would be available for 6 to 7 seconds, following which a recovery to stable operation would occur with some semi-permanent power loss.

There was no evidence that No. 3 ingested any birds. It is concluded that it operated normally from the start of takeoff until impact.

The No. 4 engine probably ingested fewer birds than Nos. 1 and 2; consequently, its power transients were least severe with substantial decrease most likely not exceeding two or three seconds. This belief is based on the indications that the starling flock was concentrated more on the left side of the airplane and lack of observations of flames on the right side of the airplane as contrasted with

observations of flames on the left side. Furthermore, the path of the aircraft suggests considerable power asymmetry with the most power being on the right side.

Except for No. 1, the engines were producing near takeoff power at impact. This somewhat limits the number of birds that may have been ingested. Wind tunnel tests indicate that power recovery is improbable when eight or more birds are ingested and it is obvious that there was recovery of No. 2 and No. 4 engines before impact.

Shaft horsepower readings obtained from the instruments are not compatible with the semi-permanent power losses that the wind tunnel tests indicated would occur following bird ingestion. Assuming the semi-permanent power losses occur as indicated by the wind tunnel tests, the instrument readings also are not compatible with the bird ingestion pattern that is known to have occurred, i.e., the SHP reading of No. 3 engine which did not ingest birds was about the same as No. 2 and less than No. 4, both of which ingested birds. Consequently, it is concluded that the instrument readings obtained are not valid criteria by which to determine the number of birds ingested by the individual engines.

Based on examination of the aircraft's primary hydraulic and electrical systems components, it can be concluded that they experienced no in-service failures prior to impact.

Since the No. 3 engine showed no evidence of power loss during the flight, its generator would be supplying electrical power for essential system units throughout. Even if generators Nos. 1, 2, and 4 were initially lost due to engine power loss because of the ingestion of birds, the No. 3 generator would automatically supply electric power to Priority Bus A; hydraulic pumps 1A and 2 would have electrical power available to them and consequently both hydraulic power systems would be available for flight control booster operation.

Using an arbitrary 3 seconds delay between lift-off and the selection of gear up, and the nominal 9.5 seconds for landing gear retraction time, a period of hydraulic and electrical capability is shown to cover approximately the first 12.5 seconds of flight following lift-off.

Six seconds after takeoff the aircraft struck a flock of birds and the No. 1 propeller was feathered. The time required to feather the propeller is approximately 8 to 9 seconds when the engine is at takeoff power. The feathering operation confirms the availability of generator power, and covers the first 15 seconds of the flight after lift-off.

During the feathering operation or a short time later, the No. 1 engine shutdown handle was actuated. One function of this control is to close the fuel cutoff and engine oil shutoff valves electrically. These valves receive their power from the Essential DC Bus and, since they were found fully closed, this condition verifies the existence of power. The Essential DC Bus is also the power source for the emergency inverter.

Had all generator capability been lost more than four to five seconds prior to impact, the emergency inverter would have started operation at the time of the electrical power loss and would have shut down automatically upon any restoration of power. Since the rundown time of the emergency inverter is approximately 13 seconds and examination of the recovered inverter disclosed clear evidence that

its armature was not rotating at impact, it can be concluded that there was no interruption of electrical power from the time of feathering the propeller to the time of impact. Hence, it can also be concluded that hydraulic boost assist to the primary flight controls was available throughout the flight.

Lockheed Aircraft Corporation undertook a series of flight tests to study the controllability of the Electra L-188 under conditions of multiple powerplant failures and operating under circumstances considerably more critical than those required for certification. Specifically, the tests determined the minimum control speed (V_{mc})5/ of the aircraft while in various bank angles, and with one or two engines inoperative. In addition, the tests defined the maximum asymmetric power at which the aircraft heading could be maintained at a constant low airspeed.

It was found that with the No. 1 propeller feathered and the other three engines developing 3,800 horsepower, V_{mc} ranged from 110 knots with five degrees of right bank to 136 knots with five degrees of left bank.

In similar tests with the No. 1 propeller feathered, No. 2 propeller windmilling, and engines Nos. 3 and 4 each developing 3,800 horsepower, V_{mc} was found to be 125 knots with five degrees of right bank and up to 154 knots with five degrees of left bank.

Another group of tests was conducted with the No. 1 propeller feathered, No. 2 propeller windmilling and various power combinations on engines No. 3 and No. 4. The aircraft was flown at bank angles of five degrees left and right. Under these conditions it was demonstrated that in order to maintain directional control of the aircraft with two engines inoperative on the left side, the total power output of both engines on the right side could not exceed the maximum power output of a single engine.

The results derived from these tests provided the Board with valuable information concerning the capabilities of the Electra under predetermined adverse conditions and also formed a basis for evaluating the operating limits which may have prevailed at the time of the accident.

The test flights did not exactly duplicate the conditions under which N 5533 was operating, in that they were conducted at constant, rather than fluctuating, engine power conditions. The aircraft at Boston, after striking the birds, experienced a power loss on the No. 1 engine which resulted in the feathering of its propeller. The Nos. 2 and 4 engines experienced an abrupt loss and nonsimultaneous recovery of power while the No. 3 engine remained at full power throughout the flight.

It was brought out during the Board's public hearing that after striking the birds and with No. 1 propeller feathered and No. 2 engine power output interrupted, it would require 3,500 total horsepower to place the aircraft at the observed points in space; more or less horsepower would have produced a different flight profile. The flight test, wherein it was demonstrated that an Electra, similarly configured, could not be controlled with more than 3,800 horsepower on its right side, tended to corroborate this.

5/ V_{mc} as used in this report differs from V_{mc} as defined in Civil Air Regulations. In this case it refers to the minimum speed at which a constant heading can be maintained under any prescribed power configuration and angle of bank.

Following the hearing, further study was made of the performance and control of the Electra under critically adverse conditions, particularly the drag aspects of large yaw angles. It was determined that the previous information on required horsepower can only be applied if the aircraft does not have a high drag count over and above that produced by interrupted power output. The excessive yaw angle associated with a flat turn of small radius produces drag to the extent that abnormally high power is required to maintain flying speed or, in fact, to prevent rapid deterioration of airspeed to the stalling point. Inspection of a plot of power required versus turning radius reveals that, at 110 knots and 10 degrees bank angle, the power-required curve becomes asymptotic at a turning radius of 2,000 feet.

The Board recognizes that N 5533 was not at precisely this speed and bank angle throughout the final stages of flight, but it was near enough to make the data applicable. It is known that the radius of the flat turn from an easterly heading to northeasterly was less than 2,000 feet. It logically follows that if the drag, which is related to power required, is many times higher than the total thrust available under any engine condition, additional thrust is available only by assuming a steep nose-down attitude; otherwise the aircraft will rapidly lose airspeed.

Calculations based on the Electra lift curve and on the deck angles reflected in the two photographs taken by witnesses produce an airspeed of 118 knots at the time of the first photograph and 103 knots at the time of the second. During the approximately 1-second interval between the first and second photograph the aircraft was approaching the stall at the rapid rate of about 15 knots per second, and at the time of the second photograph was well below the stall speed which, for the weight, flap position, and attitude of the subject aircraft, was 108 knots.

Extreme yaw angles also cause the fuselage to partially shield one wing from the airflow. The skidding turn also reduces the lift on the shielded wing. These two phenomena, together with, in this case, the additional lift due to slipstream on the unshielded wing, produce a condition commonly referred to as roll due to yaw. This condition is normally countered by aileron and rudder application to the opposite side, but becomes uncontrollable at low airspeeds where control surface effectiveness is low. There is, then, a point where the induced rolling moment is higher than the countering moment produced by control surface deflections.

In an effort to explore all facets of control difficulties that may have been encountered by the crew of N 5533, the Civil Aeronautics Board devised and observed a series of tests utilizing an Electra L-188 flight simulator owned by National Airlines and certificated by the Federal Aviation Agency. While recognizing the limitations of the trainer, the tests were designed to simulate the conditions of airspeed, altitude, and, insofar as possible, various power interruptions which might have affected the subject flight. These tests provided the Board, through qualitative observation, a more thorough understanding of the complex problems confronting the crew of N 5533 during the fatal emergency. The results of the tests made by qualified Electra pilots who flew the trainer under conditions simulating those that prevailed at Boston demonstrated that control of the aircraft, under such conditions, could have been an insurmountable task.

The total time from the start of takeoff until the crash was 47.5 seconds. It is believed that the takeoff roll and lift-off were normal. The time required

to the lift-off point was 20 seconds. The speed would have been approximately 121 knots, which was V_2 for the existing conditions. It is therefore evident that the airplane was in the air approximately 27.5 seconds.

Based on the relative locations of the bird carcasses and the point of lift-off, it is concluded that the aircraft struck the birds approximately six seconds after lift-off. Assuming a reasonable acceleration of 2 knots per second, the speed at this point would have been about 133 knots. Allowing 1 second for ingestion to occur, it would then require an estimated additional 6 seconds for total power recovery excluding the No. 1 engine. There would then be a period of 14.5 seconds remaining during which the aircraft was in the air. This 14.5 seconds would be further reduced by a 3-second interval allowed for the aircraft to plunge uncontrolled into the bay. It is recognized that these times are estimated, but it is believed they are sufficiently accurate to emphasize the extremely short period of time (approximately 11 to 12 seconds) that was available to the pilot to take effective corrective action.

From all the evidence available, the Board concludes that about 27 seconds after the takeoff roll commenced and 7 seconds after lift-off, engines Nos. 1, 2, and 4 ingested sufficient numbers of birds to cause losses of power on these engines and that Nos. 2 and 4 recovered in the manner previously described.

More important, however, the Board believes that the key to the severity, and probably to the occurrence of the accident, lies in the unique and critical sequence of a rapidly occurring chain of events.

First, the more complete loss of power on the left side than on the right started the aircraft turning to the left while its airspeed was decaying as a result of the overall power loss. The fact that the No. 1 propeller rather than an inboard propeller autofeathered, while not critical in itself, was more undesirable in that it increased the degree of asymmetry of any power combinations on the right side.

The No. 2 engine flameout, coupled with only a partial loss of power on No. 4, placed the aircraft in a condition of having no power on the left side and substantial power on the right. This produced a severe yaw to the left which was further aggravated by No. 4 engine recovering full power prior to the relight and recovery of No. 2.

The high yaw angle, as earlier described, produced a drag of such magnitude that the subsequent recovery of No. 2 engine could not arrest the rapid decrease in speed before the aircraft stalled. The recovery of No. 2 engine, while it reduced the degree of asymmetry, could not compensate for the high-power condition on the right side. With some degree of asymmetric power still producing left yaw and roll, coupled with the effects of roll due to yaw, and with the aircraft rapidly entering a stall regime, roll control effectiveness degenerated and the aircraft rolled farther to the left, stalled, and entered a spin. The only recovery from such a situation prior to the spin would have been to reduce power and lower the nose to regain control and airspeed. Recovery in this case was impossible since the 100-to 150-foot altitude was insufficient in an aircraft of the Electra's dimensions and speed requirements.

It is not unreasonable to assume that birds may have struck the windshield and may also have plugged one or both pitot heads. The startling effect of the

noise generated by the bird strike and impairment of forward visibility, in conjunction with a possible loss of airspeed indication, would certainly be disturbing elements in an already critical situation. Neither the outer windshield panels nor the pitot heads were recovered; therefore, no proof can be offered.

The Board concludes that emergency conditions of great complexity were thrust upon the crew in an increasingly deleterious environment, and that human capabilities of perception, recognition, analysis, and reaction were insufficient in the time and space restrictions of this accident to accomplish restoration of positive performance control.

It has also been determined that there was no structural failure or mechanical malfunction of the aircraft, other than has already been discussed, which contributed to the cause of the accident.

As a result of this accident and pursuant to section 701(a)(3) of the Federal Aviation Act of 1958, the Civil Aeronautics Board recommended on December 5, 1960, to the Administrator of the Federal Aviation Agency that a basic research program be initiated by the FAA aimed at improving the tolerance of all turbine engines to bird ingestion. It was also recommended that a study be made of the means of precluding bird entry into turbine engines. A comprehensive program of research into turbine engine bird ingestion has since been initiated by the FAA. Information obtained as a result of various tests which have been conducted thus far is being analyzed and should prove significant in preventing accidents of this type in the future.

The investigation disclosed the first failure points of the seat and seat belt attachments and also pinpointed injury-producing environment within the cabin. In view of these findings, recommendations were made by the Board soon after the accident with the objective of enhancing passenger safety aspects of the Electra L-188 aircraft. Based on these recommendations, considerable research was engendered which it is hoped will result in an overall improvement in passenger safety.

Probable Cause

The Board determines that the probable cause of this accident was the unique and critical sequence of the loss and recovery of engine power following bird ingestion, resulting in loss of airspeed and control during takeoff.

BY THE CIVIL AERONAUTICS BOARD:

/s/ ALAN S. BOYD
Chairman

/s/ ROBERT T. MURPHY
Vice Chairman

/s/ CHAN GURNEY
Member

/s/ G. JOSEPH MINETTI
Member

/s/ WHITNEY GILLILLAND
Member

S U P P L E M E N T A L   D A T A

Investigation and Hearing

The Civil Aeronautics Board was notified of this accident at 6:15 p.m. on October 4, 1960. CAB Investigators were immediately dispatched to the scene and an investigation initiated and conducted in accordance with the provisions of Title VII of the Federal Aviation Act of 1958. A public hearing was ordered by the Board and held in the auditorium of the Air National Guard headquarters, Logan International Airport, Boston, Massachusetts, on January 11, 12, and 13, 1961.

Air Carrier

Eastern Air Lines holds a current certificate of public convenience and necessity issued by the Civil Aeronautics Board to engage in the transportation of persons, property, and mail. It also possesses a valid air carrier operating certificate issued by the Federal Aviation Agency.

Flight Personnel

Captain Curtis W. Fitts, age 59, was employed by Eastern Air Lines December 13, 1934. He held a valid FAA airline transport pilot certificate with ratings for the Martin 202, 404, Convair 240, 340, 440, DC-4, DC-6, DC-7, Lockheed Constellation, and L-188. Captain Fitts had a total of 23,195 flying hours of which 1,053 were in the L-188. His last FAA Class I physical examination was given on July 20, 1960. He had received a line check on May 29, 1960, and an instrument check on April 7, 1960.

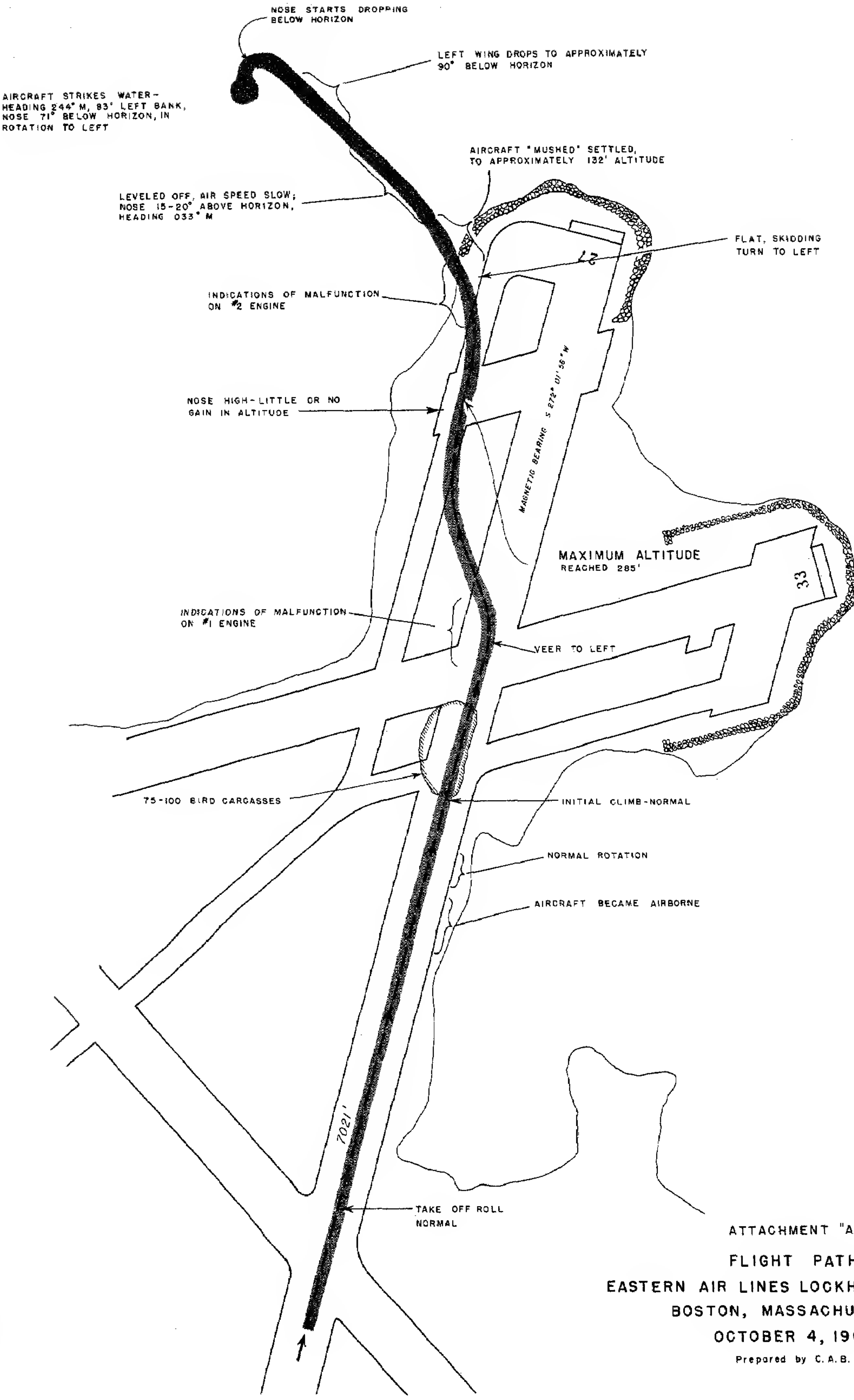
Pilot Martin J. Calloway was employed as a pilot by Eastern Air Lines on October 5, 1953. He held a valid FAA airline transport pilot certificate with ratings for Martin 202, 404, Convair 240, 340, and 440. He had a total of 5,820 flying hours of which 201 were in the L-188. His last FAA Class I physical examination was given March 17, 1960, and a line check June 7, 1960.

Flight Engineer Malcolm M. Hall was employed by Eastern Air Lines December 7, 1953. He held a valid FAA flight engineer certificate and an airframe and powerplant mechanic certificate. He had a total of 7,796 flying hours of which 369 were in the L-188. Mr. Hall's latest FAA Class II physical examination was taken December 14, 1959. His last line check was given May 20, 1960.

The Aircraft

The aircraft was a Lockheed Electra, model L-188, U. S. Registry N 5533, owned and operated by Eastern Air Lines. It was manufactured on June 8, 1959, serial No. 1062. The total time on the airframe was 3,526:29 hours.

The engines were Allison model 501-D13 with Aeroproducts propeller model A644IFN-606. No. 1 engine had a total time of 2,515 54 hours, No. 2 - 2,707·46 hours, No. 3 - 2,783:06 hours, and No. 4 - 3,144:04 hours.



ATTACHMENT "A"

FLIGHT PATH

EASTERN AIR LINES LOCKHEED ELECTRA

BOSTON, MASSACHUSETTS

OCTOBER 4, 1960

Prepared by C. A. B.

W.E.L. 5/29/61